NASA TT F-9461

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Translation of "Issledovaniye uglerodistogo veshchestva meteoritov metodom mikrodifraktsii sverkhbystrykh elektronov."
Geokhimiya, No. 4, pp. 387-390, 1965

GPO PRICE $ _____

CFSTI PRICE(S) $ _____

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

N65 29728 (ACCESSION NUMBER) (THRU) 1

(PAGES) (CODE) 06

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON JULY 1965

INVESTIGATION OF CARBONACEOUS METEORITE MATTER BY THE MICRODIFFRACTION OF SUPER HIGH-SPEED ELECTRONS

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ABSTRACT

The structure of high-molecular carbonaceous matter of /387* stony meteorites (carbonaceous chondrites) Mighei, Cold Bokkeveld, Staroye Boriskino, of the Novyy Urei ureilite and the Burgavli iron meteorite has been investigated. The investigation was carried out with the aid of super-voltage electron microscope electronography (accelerating voltage 400 kV), which ensures the allowable thickness of the object of about 1 μ. In carbonaceous chondrites the carbonaceous matter is represented by high-molecular organic compounds

*Numbers given in the margin indicate the pagination in the original foreign text.

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of an amorphous and crystalline structure with very fine black carbon. Besides organic polymers, graphite and diamond, the chief constituting phases of the carbonaceous matter of this meteorite type, are present in ureilite. In the Burgavli meteorite the chief phase is carbon-graphite; black carbon and high-molecular organic compounds are also present. The structure of the carbonaceous meteorite matter allows judging the character of evolution not only of the carbonaceous matter but also of the meteorites themselves.
Author

The present investigations were conducted by means of electronography utilizing an electron microscope with an accelerating voltage of 400 kV. The electron energy was 557 KeV and the wave length was $\lambda = 0.016$ Å (ref. 1). This device provides for a permissible object thickness of the order of 1 μ and microdiffraction selectivity up to 0.05 μ (ref. 2).

It is of considerable interest to apply the methods of structural analysis in the investigation of meteorite matter. However, X-ray structural analysis and electronography make it possible to obtain only the total diffraction spectra from relatively large amounts of the substance. At the same time, to obtain the complete characteristics of meteorite composition, it is necessary to have diffraction spectra from individual dispersed particles. When such spectra are interpreted, it is possible not only to identify their chemical composition but, even when a homogeneous chemical compound is present, it is possible to define more accurately the nature and degree of order in their crystalline structure.

Thus, for example, in the investigation of the carbonaceous matter of meteorites, it is possible to clarify substantially the amorphism of investigated particles and the degree of their graphitization. To solve problems of this type, modern structural crystallography uses the method of microdiffraction, which combines electron microscopy with electronography. In this case, the images of investigated particles and their diffraction spectra are observed in the electron microscope. However, the conventional electron microscope with an accelerating voltage up to 100 kV does not give satisfactory results for such microdiffraction investigation because of the low penetrating capacity of electrons and because of the insufficient selectivity of microdiffraction. When the energy of electrons is raised to relativistic velocities, the permissible thickness of particles increases and selectivity also increases, i.e., the selectivity associated with obtaining a diffraction spectrum from an observed particle. We call the high selectivity microdiffraction associated with the application of high energy electrons, the microdiffraction of super high-speed electrons (refs. 1-3 and others).

Our investigations were concerned with the study of the carbonaceous material of stoney meteorites -- carbonaceous chondrites Mighei, Cold Bokkeveld, Staroye Boriskino and diamond-bearing achondrite -- Novy Urei ureilite and the Burgavli iron meteorite octaedrons with coarse structure. Preceding investigations (refs. 4-6) have shown that a carbonaceous substance which is uniformly distributed between silicate inclusions in stone meteorites and which, together with troilite, forms globules in iron meteorites, consists of a mixture of compounds. In carbonaceous chondrites whose carbon content reaches 4.8 percent, it enters primarily into the composition of high molecular weight matter. A certain portion of it is contained in the bituminous matter which is extracted

by means of organic solvents, while some of it is in the form of elementary carbon. These three components form the so-called carbonaceous matter of this type of meteorite. In the carbonaceous globules of iron meteorites, graphite is present in addition to the carbonaceous substance while in some stone /388 meteorites, diamond is also present. The purpose of our work was to investigate the high molecular weight portion of the carbonaceous substance, graphite and diamond of meteorites.

The separation of carbonaceous material was carried out by decompositing the mineral phase which contained it (ref. 4). The fractions of the carbonaceous material were dispersed with ultrasound at a frequency of 1 megacycle. Some of the results of the investigation are shown in figures 1-4.

The structure of the carbonaceous material in the investigated carbonaceous chondrites is approximately the same. Earlier it was assumed that it is either amorphous or has a crystalline nature. The microdiffraction investigation has shown, however, that the principal part of the carbonaceous material of these meteorites is a high molecular weight organic substance and consists of a mixture of polymers, which are not only amorphous (fig. 1a), but which also have a crystalline structure (fig. 1b) with tiny inclusions of finely dispersed material of the black carbon type with traces of individual particle graphitization. The presence of crystalline structure in the polymers of carbonaceous chondrites is also uncovered when they are analyzed by means of electronography, carried out by us, using the same device operating as an electronograph. Figure 2 shows the textured polycrystals of the polymers contained in the Staroye Boriskino meteorite. In figure 2a the polymers are rotated from a position perpendicular to the electron beam by an angle $\varphi = 45^{\circ}$ while in figure 2b this angle is 67°.

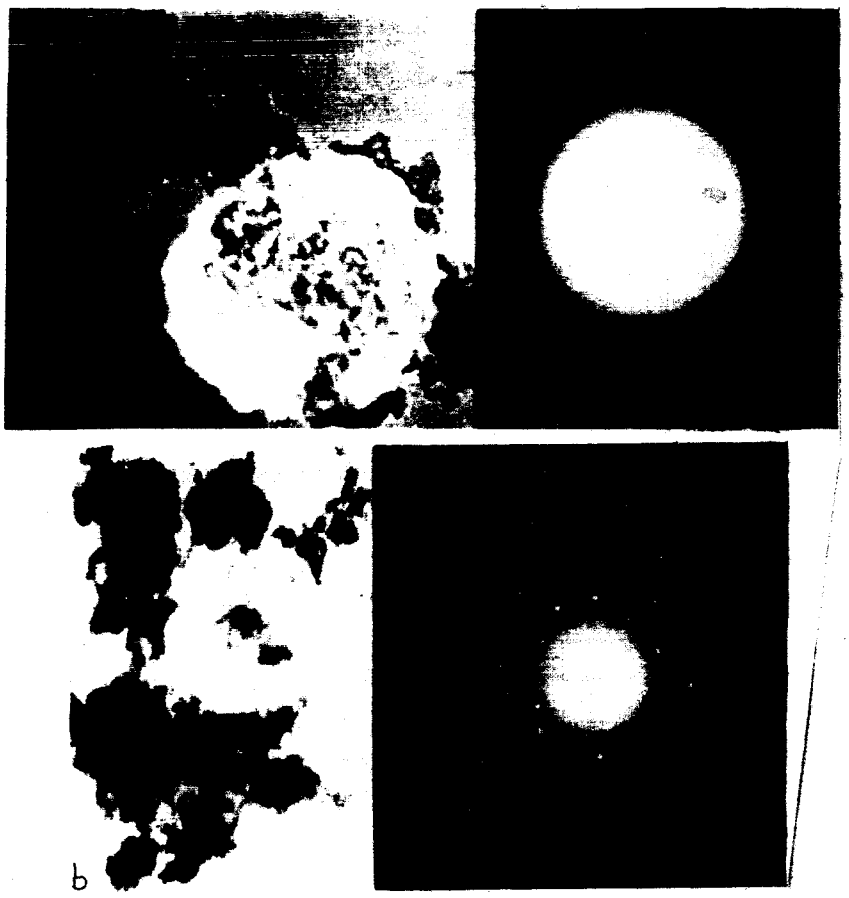

Figure 1. Full brightness images and diffraction spectra of heavy molecular weight organic substances of carbonaceous chondrites; a, amorphous polymers, Cold Bokkeveld meteorite; b, crystalline polymers, Migei meteorite. Effective diameter of selector diaphragm is 1μ.

Thus in carbonaceous chondrites, the carbonaceous material consists of a complex mixture of compounds with various degrees of crystallization from amorphous heavy molecular weight organic substances to graphitized substances in which there is a regular arrangement of carbon atoms in the chain.

In ureilites, which are a different type of stone meteorites enriched with carbon, the basic component phases of the carbonaceous material are

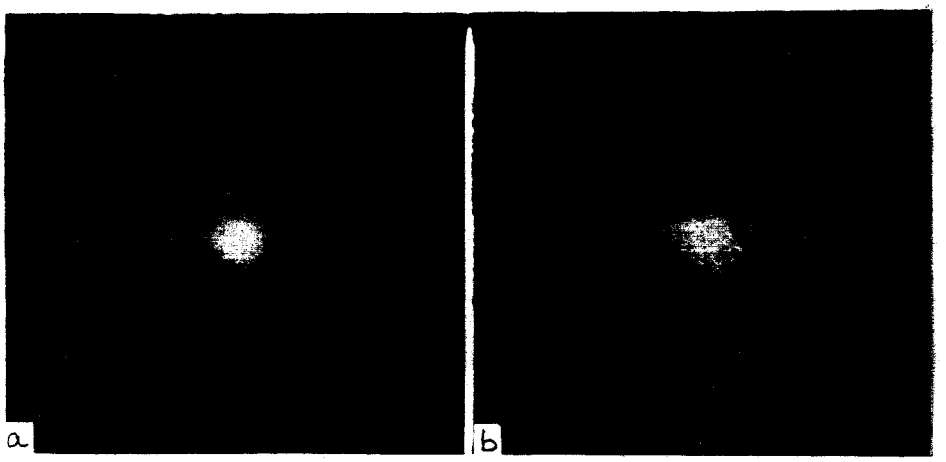

Figure 2. Electronograms of oblique textures of the high molecular weight organic substance of the Staroye Boriskino meteorite.

graphite and diamond. Graphite sometimes forms good micromonocrystals. The lauegram of such a graphite monocrystal, which contains traces of residual deformation, is shown in figure 3a. High molecular weight organic substances are also present in insignificant quantities. In most cases, the latter is contained in a mixture with graphite (fig. 3b). The diamond inclusions in turn are represented by polycrystalline aggregates in which, in addition to diamond, two other phases are present, primarily graphite and to some extent, carbonaceous material (fig. 3c).

The carbonaceous material of iron meteorites, among which the meteorite Burgavli was investigated, consists primarily of graphite. Sometimes finely dispersed inclusions of black carbon are noted (fig. 4a). In the carbonaceous globules of iron meteorites there are also high molecular weight organic substances, both of crystalline (fig. 4b) and amorphous (fig. 4c) structure. In this case, from the morphological point of view, the crystalline polymers most frequently have the form of monolythic inclusions of

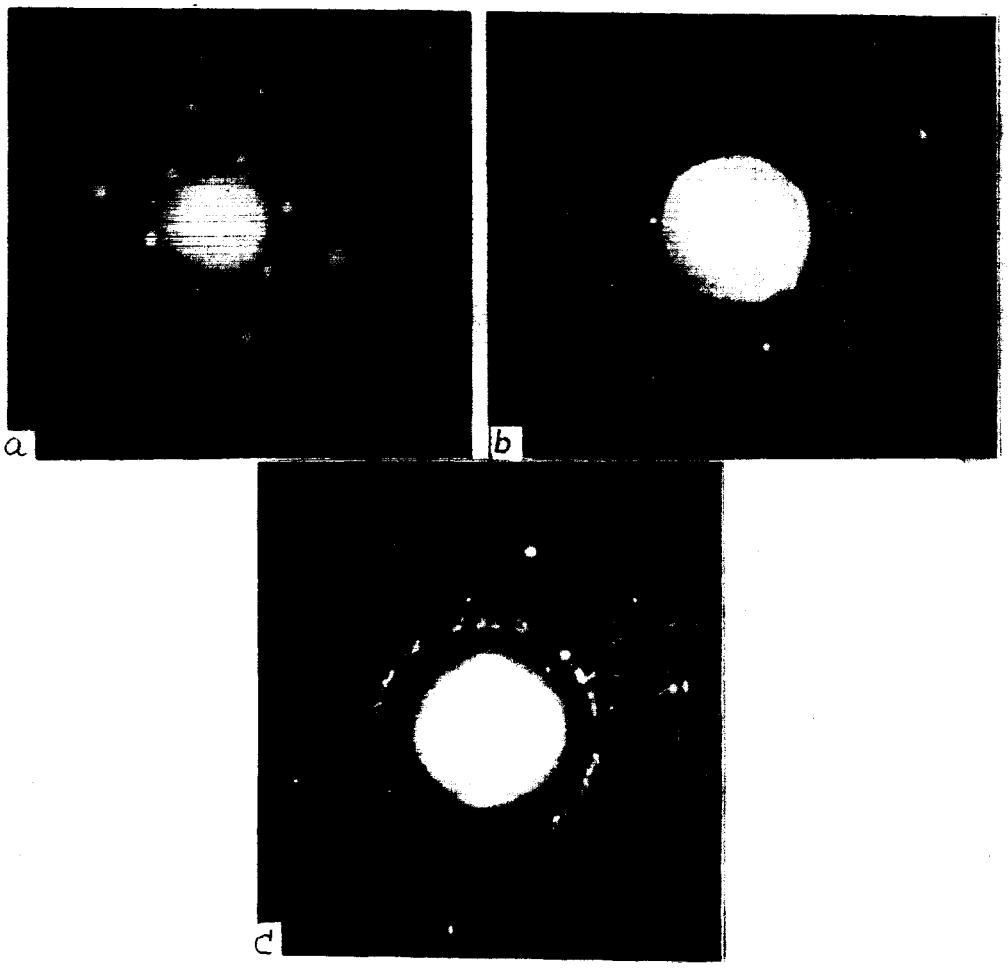

Figure 3. Microdiffraction spectra of the particles of carbonaceous material of the Novyy Urei meteorite; a, graphite; b, graphite and high molecular weight organic substance; c. diamond.

fibrous structure (a typical example of a fibrous structure both on the image and on the diffraction spectrum is shown in figure 4b); the amorphous particles on the other hand, are of the flocculent nature.

The structure of the carbonaceous matter in the investigated meteorite showed that these types of meteorites were formed under different conditions. The carbonaceous chondrites with a prevalence of high molecular weight organic

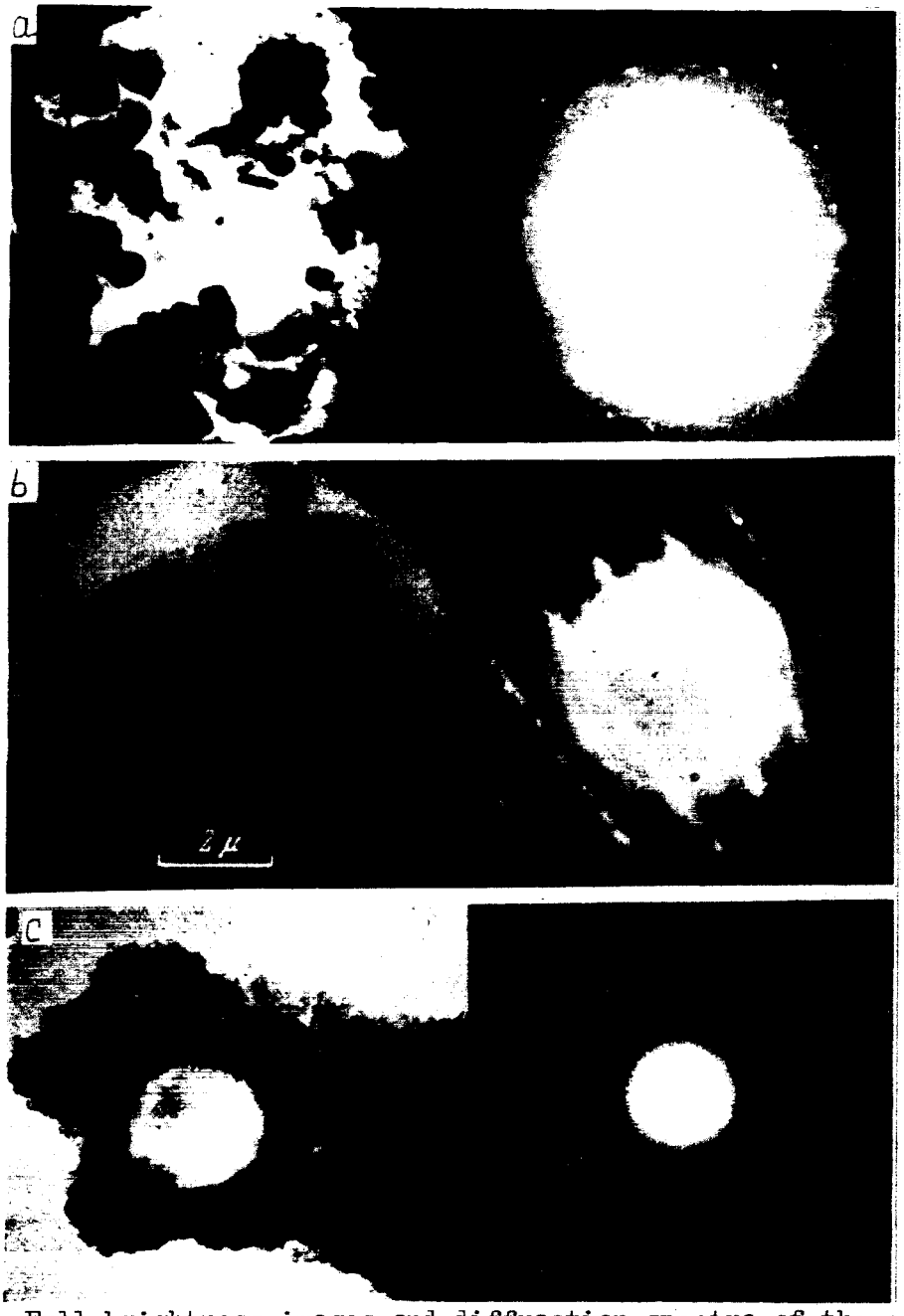

Figure 4. Full brightness images and diffraction spectra of the carbonaceous material from the Burgavli meteorite; a, black carbon with specially applied aluminum as a reference standard; b, fibrous texture of crystalline high molecular weight organic substance, the Debyé rings pertain to the standard reference-aluminum; c, amorphous high molecular weight organic substance, the effective diameter of the selector diaphragm is 1 μ.

substances were apparently formed in a medium where the temperatures and pressures were less than for the case of iron meteorites. The ureilites which also contain high molecular weight organic substances in addition to graphite and diamond were most probably formed like the carbonaceous chondrites at low temperatures and pressures; however, their substance later underwent a short-term recrystallization during the impact process.

Thus, the carbonaceous material of meteorites is of complex composition. In carbonacious chondrites it consists primarily of high molecular weight organic materials having an amorphous as well as a crystalline structure. Ureilites, in addition to graphite and diamond, also contain high molecular weight organic substances. The carbonaceous globules of iron meteorites contain organic polymers in addition to graphite. The structure of the carbonaceous material of meteorites makes it possible to judge the nature of development, not only of the carbonaceous materials, but of the meteorites themselves. The present investigation has shown that the method of microdiffraction of super high-speed electrons is a promising method in the study of meteorites.

The chemical composition of individual fractions of organic material and of carbon were also studied. We shall present data on these in the next communication.

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